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DELTA EXPERIMENTS.*

BY

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INTRODUCTION.

There are numerous papers of merit in which the form, structure, and mode of formation of many of the great deltas of the world are described in detail. These papers give accounts both of the active deltas of the present time, and of the old high level deltas, whose lakes have vanished. In this paper, it is proposed to record the form and mode of formation of several experimental deltas, and to point out and discuss the several necessary and modifying conditions of delta formation, as determined by these experiments; and also to compare these deltas with those formed in nature.

The conditions of the experiments were regulated so as to exclude all factors not essential to normal delta development. Wind, waves, tides, currents, fluctuating water level, variations in the size of the stream, salt water, and vegetation, all factors tending to modify the growth or form of a delta, were avoided. It is believed that only the essential delta forming processes were at work.

As is well known, a delta is a deposit of detritus built up by a river at its mouth on entering a practically currentless body of water, as a lake or sea. The fundamental principle of all delta formation is the law that the amount of material carried by a stream decreases with decreasing stream velocity. The momentum of a river is communicated, on entering a lake, to such a large body of water that its energy is dissipated. The current slackens, and the detritus sinks to the bottom, at varying rates, depending on the current, and on the size, specific gravity, and shape of the individual particles. As the particles brought down by a stream vary much, it is evident that there will be much sorting done.

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*The experimental work of this paper was conducted in the wet laboratory of the Geological Department, Ohio State University. To Dr. Hubbard, under whom the work was carried on, the author wishes to express his thanks and appreciation for the counsel and many invaluable suggestions, which were so kindly given.

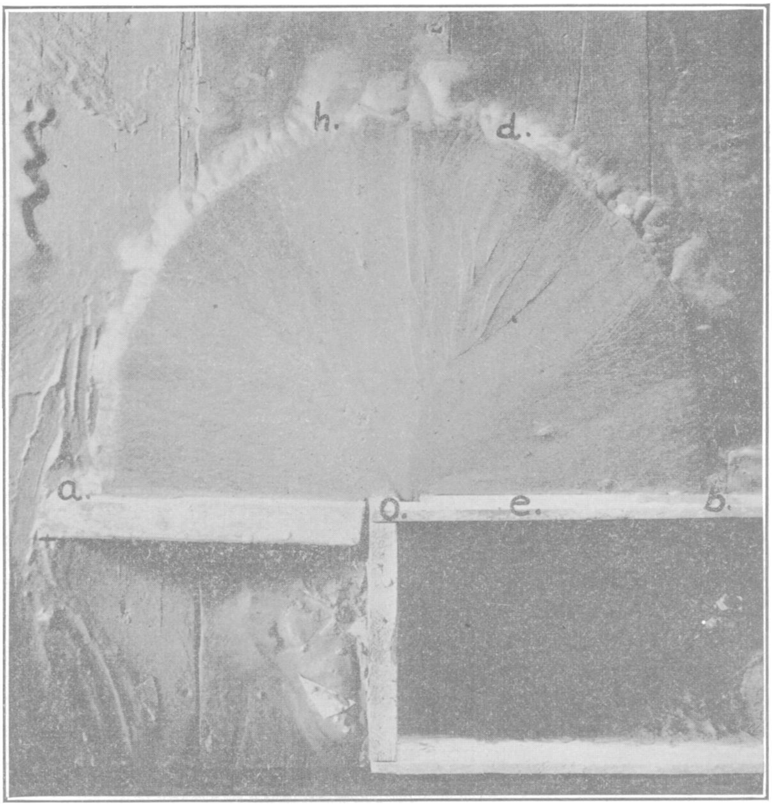

FIG. 1—A SEMI-CIRCULAR DELTA.
Looking down from above: *o* is the apex where the stream enters; *a* and *b* are points on the coast line.

In the experiments, two general forms of deltas were found. (1) A form with regular semi-circular coast line, and (2), a form with markedly irregular coast line, due to the development of lobes, which are really small independent deltas clustered around an older delta mass. The second is a later development of the first, but under changed conditions of deposition. Small deltas only were made, but they show the form and structure to good advantage. The formation of the semi-circular type will be described first.

Most of the apparatus used is shown in Fig. 1. The platform in the illustration was placed in a large tank, provided with an adjustable overflow. A long box to hold the sand, having a narrow slit in one corner, was placed on the platform, and the stream, falling about 12 inches from a glass tube syphon (bore=⅛ inch), discharged into it directly upon the sand, the material of which the delta is to be made. The syphon was used in order to furnish a uniform supply of water, since the water works pressure is quite variable.

The operation of starting a delta was as follows: (1) Fix the platform in position, (2) adjust the overflow so as to give the depth of lake desired, (3) fill the tank with water, (4) fill the feed-box to just above lake level with an easily moved material: (an exceedingly fine sand from an extinct local glacial lake was used), (5) start the syphon. The water flows down the sand incline, out into the lake through the slit in the box, and immediately begins depositing the coarser part of the sand it has carried out.

FORMATION OF THE DIFFERENT DELTA BEDS.

The amount of material carried by a stream varies both with the gradient and the character of the material, according to well-known laws. From the standpoint of delta formation, the stream carries detritus in two essentially different ways. (1) The finer material is carried in suspension, and (2) the coarser is rolled or saltated along the bottom. On being emptied into the lake, these two classes of detritus behaved differently. The stream has enough momentum, so that its velocity is not entirely checked for some distance after entering the lake, consequently much of the finer suspended material is carried out some distance before settling. Most of it falls not far from the stream mouth, forming here strata of very fine material, which feather out on all sides. They are nearly parallel to the lake floor, and are known in general as lake clays. When, however, they are covered with a true delta deposit, they are called *bottomset* material, and are generally considered part of the delta. See Fig. 2 for the position of this material, and the beds to be described later.

The coarser material rolled and saltated along the bottom, on the other hand, tumbles immediately into the lake, soon building up to lake level a stratified mass of sand, the outer slope of which is as steep as the sand grains will lie in water. In the fine sand used, this angle of repose was very close to 34°. Layer after layer is added to the delta front, all inclining at approximately the same angle. As may be seen in Fig. 2, these layers extend from about lake level down to the top of the lake clays, into which they tend to grade at the base by a gently curved transition. These layers, each at one time marking the delta front, are known as *foreset* material. They are composed, as may be seen in the figures, of much coarser material than the lake clay.

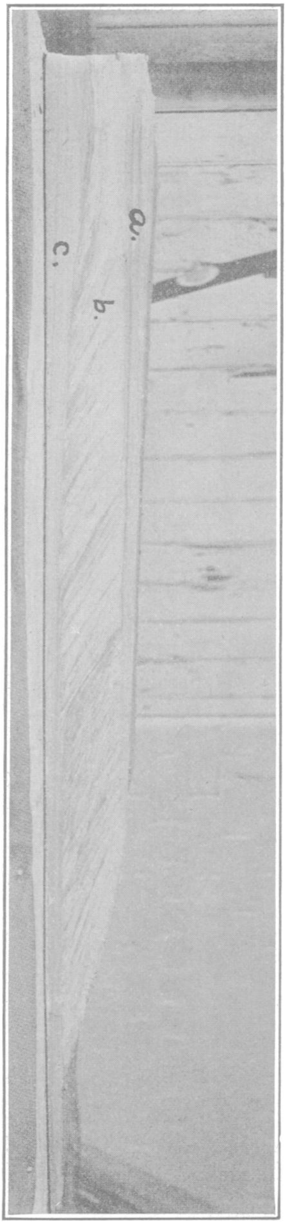

FIG. 2—A DELTA SECTION.
Parallel to the radial. *a*, topset beds; *b*, foreset beds; *c*, bottomset beds.

The forward building of the delta tends to extend the stream lakeward exactly at water level, without any gradient whatever. Obviously, then, the velocity of the stream is checked on entering this level stretch, and material is immediately deposited over it. This deposit, in its turn, now checks the velocity of the stream immediately above it, causing deposition there. By the up-stream advance of this area of retardation, the whole of the stream course over the delta plain is finally raised, and a stratum with a gradient similar to that of the stream is added on top of the delta.

In reality, this deposition begins as soon as the first foreset bed has reached its maximum upward development, *i. e.*, nearly to lake level*, and continues, layer for layer, with the increase in the number of the forset beds. The formation of the two kinds of beds goes hand in hand, as may be seen from the fact that each layer of one kind is directly continuous with one of the other. (See Fig. 4.) The number of these layers and, consequently, the thickness of the deposit is greatest at the apex of the delta. The deposit thins out regularly from that point to the delta edge. This deposit is called *topset* material.

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* See p. 740.

ORIGIN OF THE SEMI-CIRCULAR DELTA OUTLINE.

So far it has been assumed that the stream was building a long narrow delta straight out into the lake, but it is obvious that the stream will keep changing its course so as to follow the steepest grade, hence the shortest route to the lake. While building up foreset beds in one place for some time, the stream is lengthened, and consequently the stream bed is raised, and at the same time the grade is lowered. Soon a break occurs in the banks, and a new route to the lake is found. This break may occur in the main stream, or in one of its distributaries. In the experiments in which a constant volume of water is used, and hence no floods, the stream was found to swing from side to side of the delta, with no very definite breaks. The branches gradually silted up and shrank on the side of lesser grade, and undercut and expanded on the other. Thus the stream systematically migrated across the delta depositing a topset layer as it went. By using irregular amounts of water, producing floods, the breaks were more definite, yet the regular lateral migration was no less pronounced.

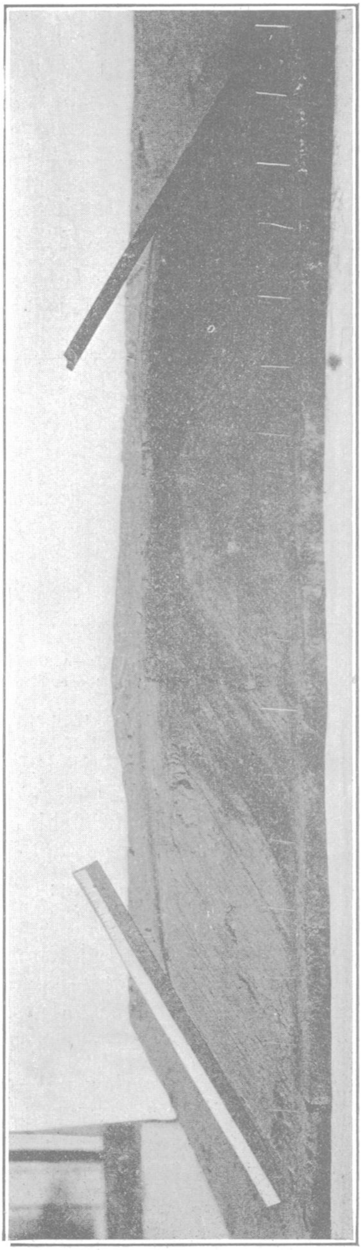

FIG. 3—A BASAL DELTA SECTION.
Along line *a b* of Fig. 1.

From the preceding description, it will be seen that the whole of the topset material has the form of a fan, *i. e.,* the half of a very flat cone. The growth of the fan really determines the course of the stream, and hence the shape of the delta. Under conditions of uniform deposition, as made by a stream of constant velocity, volume, and load, it was not found possible, in an open sea, to make other than a quite regular semi-circular delta.

DISCUSSION OF THE DELTA SECTIONS FIGURED.

Different sections of the delta show characteristic arrangements of these three different kinds of beds. Fig. 4, a radial section, as along the lines *oh* or *od* of Fig. 1, shows an excellent development of the foreset beds. Their uniform dip and similarity is noticable.

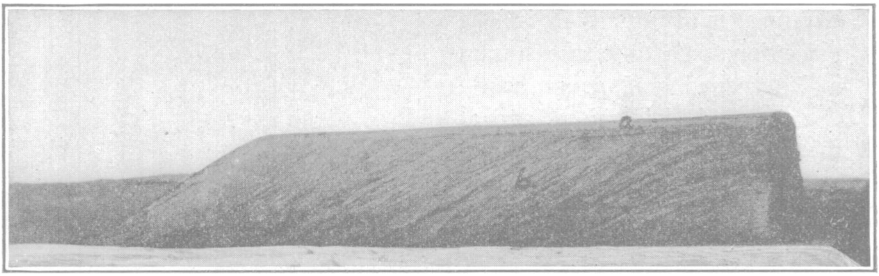

FIG. 4—A RADIAL DELTA SECTION.
a, topset beds; *b*, foreset beds.

The nearly horizontal bedding in each of the foreset layers in this section is a peculiar feature. This bedding was found in all sections of deltas made, but so far as is known, its formation has never been watched in the field, nor has it been more than obscurely mentioned in delta reports examined. The method of formation of the phenomenon is as follows: A slight oversteepening of the upper part of the delta front, just below the stream mouth, results from the dumping and immediate lodgment here of the coarser detritus, which does not tumble, particle by particle, down the slope, as might well be imagined. Material accumulates at this point till finally an unstable condition results. Then the whole mass begins to flow quietly down the delta front in a rather narrow stream. At the base, the mass spreads out, and at the conclusion of the flow, the pile resulting is nearly flat-topped. After a time there are more accumulations on the upper part of the slope, and further flows result. Each spreads out on top of the last, and always retains a flat-topped upper surface. Finally the foreset bed is built up about to water level. It will thus be seen that each separate bed is completed at each point, before another is begun. The completion of a bed is enough usually to cause the stream to shift, so that very often one foreset layer around the whole delta is completed before another is begun. In none of the sections, were these layers more than a half inch thick, but their size is presumably limited by the coarseness of the material, and height of the delta front.

In Fig. 2, a section of another delta along the line *de* in Fig. 1, a marked development of all three classes of delta deposits is shown. Here Gilbert's description* is very well illustrated.

> "Any vertical section of a normal delta exhibits at the top a zone of coarse material bedded with a gentle lakeward inclination, then a zone of similar coarse material, the laminations of which incline at a high angle, and at the bottom, a zone of fine material, the laminations of which are gently inclined and unite by gentle curves with those of the middle zone."

Fig. 3, a section along the base of a delta parallel to the old shore line, along the line *a b* Fig. 1, exhibits a markedly distinct zonal arrangement. The foreset beds, it will be seen, slope both ways from the center or apex of the delta. The beds formed by the deposition of the coarse material at the initial stream mouth, and the development of foreset beds on either side of this central mass, are well shown. The topset beds range in thickness from zero at lake level on one side up to the maximum in the center and down again to zero on the opposite side. This section is really equivalent to two radial sections fitted together at the apex. It is a diametral section.

ORIGIN OF THE IRREGULAR LOBATE DELTA.

Thus far only the semi-circular type of delta, formed under conditions of constant or increasing load, and uniform velocity and volume of water has been considered. If the amount of detritus in each unit volume of water is lowered, the nature of the stream is changed. Instead of aggrading, it is degrading. Stream beds are cut down, instead of being raised, and soon the stream and its distributaries have all sunk down to a new grade, below the general delta plain, but, of course, not down to lake level, except at the delta edge. This entrenched river system is now stationary, instead of being migratory. It does not move about over the delta plain. The material brought down by the distributaries is dumped in front of the mouth of each, and soon a protruding lobe develops there, which acts in all respects like a delta of the first class. The little stream swings back and forth, and builds up a uniform semi-circular lobe. Each distributary, of course starts a little new delta of its own; but as the distributaries are often very close together, the little deltas coalesce in part, and form a marginal fringe, from which their fronts protrude (see Fig. 5). These little lobes might be confounded with delta fingers, but as will be shown further on, they conform to none of the requirements of a finger.

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* Gilbert, loc. cit. (a.), p. 69.

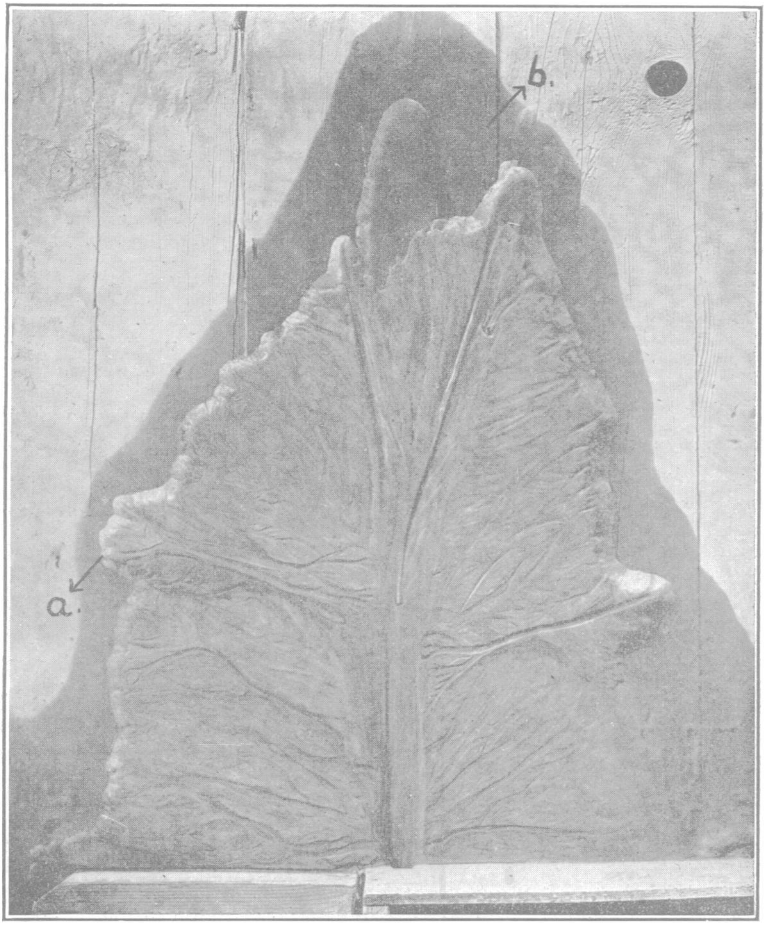

FIG. 5—AN IRREGULAR, LOBATE DELTA.
Looking down from above.

When the different lobes of a compound delta coalesce, there is always much interference with the normal development of the foreset beds. One lobe finding itself blocked by the previous deposition of another, fills up along side. The foreset beds of the first, inclining in one direction, now underlie the foreset beds of the other, which may be inclined in any one of a great number of directions with reference to the first, depending (1) on the relative positions of the centers of origin of the two lobes, and (2), on the relative size of each. It will be seen that any number of complicated relations may exist between the two beds.

By sectioning just back of the lobate margin, as on line *ab* of Fig. 5, much cross-bedding is found, as is shown in Fig. 6. The inclination of the beds and their relations to one another were found to change greatly in a few inches. It will be noticed that in the figure this cross-bedding occurs only in the foreset beds, and that the topset and bottomset beds are without it.

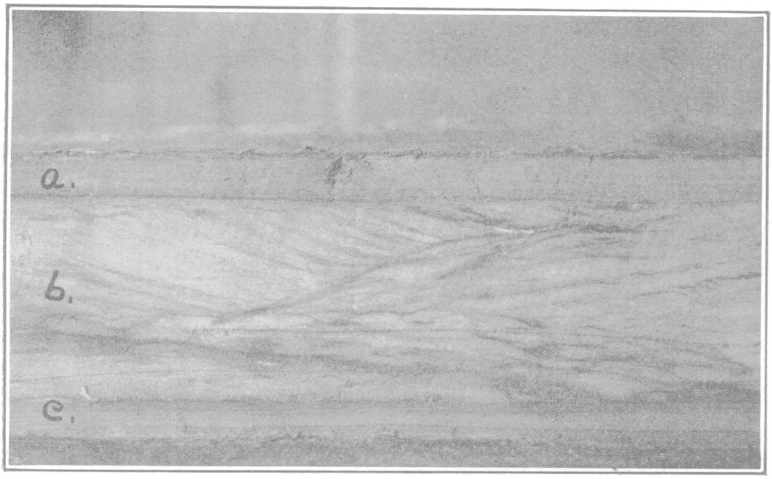

Fig. 6—A SECTION OF A LOBATE MARGIN.
As along *a b* of Fig. 5. *a*, normal topset; *b*, cross-bedded foreset; *c*, normal bottomset beds.

It must not be understood, however, that cross-bedding occurs only in the foreset layers. It is true that the phenomenon is much more evident in these layers than in either of the others. In the topset beds, cross-bedding also occurs, but it is very different in character and origin from that first mentioned. In the topset material, the cross-bedding was but poorly pronounced, and minute, and moreover, contiguous beds, which were out of horizontal, did not incline at the same angle. In the foreset beds however, cross-bedding, when present, was very coarse and pronounced, and there were usually several layers together which inclined at the same angle.

INFLUENCE OF THE STREAM HABIT ON THE DELTA FORM.

The question as to whether the delta shall remain simple and semicircular as when first built, or whether it shall be slightly dissected and receive marginal lobes, is one of equilibrium, and is not dependent upon changes in level of land or of sea. If the conditions of deposition are uniform, a nearly uniform grade from apex to circumference will result. The topset layers will all be deposited parallel to one another, and will in turn all be parallel to the gradient of the stream, which latter will remain constant, allowing the stream to swing freely. These conditions are purely aggradational.

If the amount of deposition is increased, the upper and lower topset layers will not be parallel, yet this will neither affect the upper growth of the delta, nor the ease with which the stream swings. A more steeply inclined fan will be superimposed on the first, and the manner of deposition will not be changed.

But let the stream cease to carry as much detritus for each unit of water, and a very far-reaching change ensues. The river changes from an aggrading to a degrading stream. The delta river system becomes stationary and subsidiary deltas develop around the central mass. Each one of these little deltas comes to equilibrium, if the conditions of deposition remain constant. Conditions of constant or increasing stream gradient over the delta plain produces a simple delta: a decrease in the stream gradient over the delta plain produces a compound delta.

RELATION BETWEEN RATE OF FORMATION, STRUCTURE AND FORM.

The rate of formation has no effect on the essential structure or general outline of deltas. The delta whose section is given in Fig. 4 was twenty-five days in building, while the one in Fig. 2 was built in less than one, yet in all essential respects, they are similar. So, too, the semi-circular delta, Fig. 1, built in 30 minutes, is nearly identical with another which required twenty days to build.

The quickly formed delta has a much greater development (1) of the bottomset beds, due to the strong current carrying much of the finer material beyond the delta edge; and (2) of the topset beds, due to the much steeper gradient required by the rapid, heavily-laden stream. In this form of delta, the foreset beds also lack somewhat the pronounced definiteness they exhibit in the more slowly formed delta; and they are larger. The differences are merely in degree of development.

DELTA FINGERS.

At the beginning of the experiment, marked delta fingers were expected, but the only ones formed were small. It was found on trial that they are merely a superficial marking of the delta edge, and that they are not built out independently in front of the delta proper. The popular idea, presumably derived from school geographies, that fingers constitute a distinguishing characteristic of deltas, is far from true. Fingers characterize the fronts of many delta plains, but they can not be considered more than an incidental phenomenon, produced under special conditions. Coast survey charts of the world* show that fingers are only superficial features of the delta edge, and that they all lie on top of the delta proper. In the case of the Mississippi Delta (see Fig. 7), for instance, if a line be drawn connecting the different finger tips, it will mark in a general way, the extent of the delta. The open water inside this line lies on a part of the delta plain, which has not yet been built up by a few feet to sea level. Here the water will usually be found to be less than 20 feet deep, but outside of this line, the sea becomes rapidly deeper.

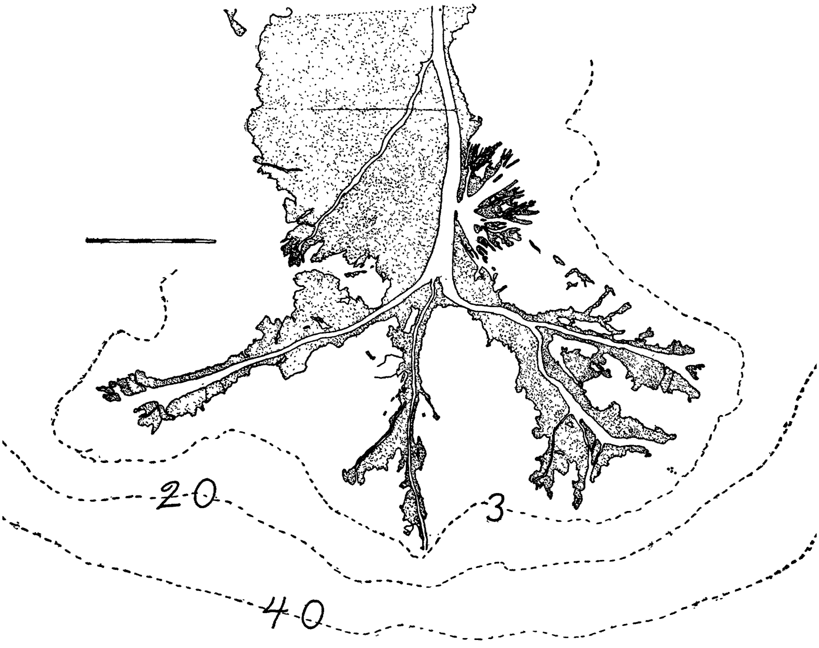

FIG. 7—THE MISSISSIPPI DELTA FINGERS.
With 3, 20, and 40 fathom contour lines. 1 division of scale=1 mile. (From Coast Survey Chart 194.)

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* See p. 742.

In considering a delta it is necessary always to remember that the actual delta shore is very often separated by quite an extent of shallow water, generally less in depth than the discharging stream, from the real delta edge, where the steeply inclined foreset layers begin (see Fig. 8).

In the experimental deltas of very gentle incline, this shallow water around the coast was a very noticeable feature, and in these deltas, fingers were nicely developed. But in the steeply inclined deltas, this submerged portion was very small, too small, in fact, to permit the growth of any fingers. In reality, the topset material or fan always begins below water level, and gradually rises above the lake toward the apex. The extent of this submerged part of the delta depends, (1) on the depth of submergence of the real delta edge, and (2) on the gradient of the topset layers. The first is involved in such complex relations with the second that it has not been attempted to work out the problem. In this shallow marginal water, fingers are developed by the lateral deposition of detritus, forming banks through which the stream flows. These fingers are formed like true fingers, and occupy an equivalent position on the delta.

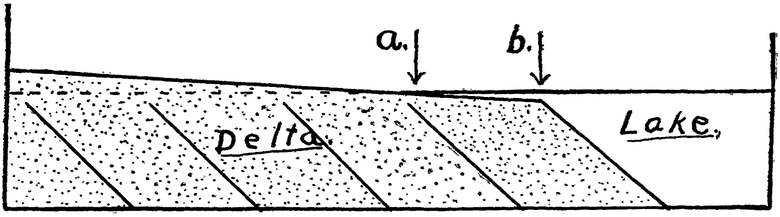

FIG. 8.
Diagram, showing relation between the delta edge *b*, and the delta shore *a*.

RELATION OF DELTA FORM TO DEPTH OF WATER, BASIN SHAPE AND LAKE FLOOR.

From the foregoing discussion of delta building, one would not expect the depth of water in the lake to make any difference in the coast contour, or in the shape of the delta fan. The differences due to deeper water are (1) the greater development of the foreset beds, and hence (2) the slower growth of the delta surface. By using different depths of water from ½ to 6 inches, this was found to hold.

Neither should one expect any difference in contour due to an irregular lake floor. Where the depth is greater, the stream deposits longer. At each point on the circumference, the stream deposits for a length of time proportionate to the depth of water. The grade is merely not so quickly changed by extension in the deeper places. By depositing a delta on a sloping floor, so that it ranged in depth from 0 to 1½ inches, a regular semi-circular outline was maintained.

The results in the two preceding paragraphs do not agree with Goldthwaite's* statement that the development of lobes (deltas) may be imperfect or wanting, because of the shallowness of the lake, or the irregularity of the lake floor. Yet because of the weight of the experimental evidence, it is still felt that the conclusions are valid.

There is a direct relation, however, between the shape of the basin and the form of the delta. The true fan-shaped delta is formed only when the coast is free, so that it may develop. Obstacles of various sorts were placed, so that deltas formed around them. In all cases the delta developed a normal shape, the obstacle being merely surrounded. The only difference in deposition being that on the lakeward side, the foreset layers were confusedly bedded for a short distance. Obviously, if a delta is formed in a narrow bay, its lateral extension will be determined by the shores of the bay. The fan-shaped upper surface will always maintain the form of a sector of a cone.

Summary of Conclusions.

1. The experimental results and the formation and structure of deltas in nature, as described by Gilbert, agree in all essential features.

2. There are two general forms of deltas, as follows:

   (a). Those with regularly semi-circular outline.

   (b). Those with irregularly lobate outline.

3. The ultimate form of a delta was found to be determined by the maintenance of a constant or increasing stream gradient, in the first case; and by the decrease of the gradient of the stream, in the second.

4. Pronounced cross-bedding was found to occur only in the foreset layers of the lobate form of delta, and, to a small extent, in all topset beds.

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* Goldthwaite, p. 271, loc. cit. in bibliography.

5. Fingers, as determined by experiment, and by the examination of coast survey maps, are only surface features of the delta margin.

6. Neither the depth of water nor the irregularities in the lake floor were found to affect the form of a delta. But, necessarily, the delta shape was determined by the shape of the basin in which it was formed.

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MAPS.

The following maps were found especially well adapted to show the superficiality of fingers:

U. S. Coast Chart No. 194, of the Mississippi Fingers.

U. S. Survey of Northern and Northwestern Lakes. Lake Saint Clair Sheet shows the Saint Clair Delta.

Swiss Survey Maps. The Agno Sheet and the Stockhorn Sheet each show by contour lines the form of the deltas.